D1.4 SUMMARY OF EXPERIENCE ON WEBGIS UTILIZATION AND MOBILE EARLY WARNING SYSTEM FOR WATER REUSE

1ST VERSION

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Abstract	This deliverable reports on the implementation of a new section in WebGIS Acque di Lombardia, dedicated to water reuse from CAP WWTP, in order to create a platform for improved decision making in water reuse.

Dissemination level of the document

X	PU	Public
	PP	Restricted to other programme participants
	RE	Restricted to a group specified by the consortium
	CO	Confidential, only for members of the consortium

Versioning and contribution history

Version*	Date	Modified by	Modification reasons
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D1	04/10/2021	UNIMI	Add partial detailed contents to chapter 2-3-4
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R	12/11/2021	CAP–UNIMI-UNIVPM–ISS	Revision after internal review
S	24/11/2021	CAP–UNIMI-UNIVPM–ISS	Ready for submission
S2	10/03/2022	CAP–UNIMI-UNIVPM–ISS	Integrated with reviewers' comments

* The version convention of the deliverables is described in the Project Management Handbook (D7.1). *D* for draft, *R* for draft following internal review, *S* for submitted to the EC and *V* for approved by the EC.

Note that previous versions to *V* are draft since they are not yet approved by the EC.

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Executive summary

This report describes the WebGIS application developed in order to improve urban data sharing and interoperability. The aim is to upgrade WebGIS Acque di Lombardia to integrate quality and risk information from Peschiera Borromeo plant and also the map of the wastewater treatment plants (WWTPs) in the Milan metropolitan area where treated effluents meet or can potentially meet the minimum quality standard for water reuse.

The WebGIS will gather cross-sectorial knowledge on water management, urban planning, and farming featuring multi-layer analysis of water demand, crop growth, climate, land use, water stress, water quality, and irrigation performance.

Characteristics of treated water are obviously related to wastewater treatments, but also to other components of Integrated Urban Wastewater and Reuse System (IUWRS), i.e. catchment, sewer network, irrigation system, and irrigated field. For this reason, the first part of the report (**Section 1**) describes the IUWRS.

Section 2 includes the description of the WebGIS Acque di Lombardia, showing the main components and functions of the current platform and the architecture of the new site, developed within DWC project to share data about wastewater reuse.

Then, in **Section 3** new layers are presented, showing water characterization for the WWTPs available for water reuse and describing areas potentially served by these plants.

Peschiera Borromeo case study is presented in **Section 4**, with a description of the WWTP and the DWC plot. A description of the purple district identified for the Peschiera Borromeo WWTP is reported. Purple district represents the area in which treated water reuse is optimized with a pipe pressurized distribution system that feeds high-efficiency irrigation methods at the field scale.

Finally, a description of the potential integration between Early Warning System and the new site of WebGIS is reported in **Section 5**, in order to provide a tool for Risk Management.

This report is a draft version of the final report that will be delivered in M42 (November 2022). The final report will keep the same structure but will bring additional input regarding

- The creation of a new layer including areas potentially served by WWTPs and cultivable crop
- The development of new tools to provide information about water reuse
- The integration of tools related to the Risk assessment
- The usability and acceptability of the solution, with feedback from stakeholders (irrigation consortia, ATO, ARPA, CoP)

Furthermore, this report includes some changes due to external comments:

- Addition of paragraph 2.3, to provide a general overview and a schematic diagram of the data integration;
- Addition of paragraphs 3.3 and 4.3 to clearly present the results of the integration;
- Moving of paragraph 4.2 from Section 2 to Section 4.

In addition, the executive summary has been updated according to the new structure of the report.

1 Introduction

Wastewater treatment needs a constant and integrated monitoring, since removal efficiencies are strictly related to process parameters. Moreover, treatment efficiencies in WWTP are also affected by varying conditions and unexpected events that can occur along all the integrated wastewater system, from the catchment area to the treatment train.

A huge amount of data need to be monitored and elaborated, in order to obtain useful information for plant management and decision making. The WebGIS platform Acque di Lombardia, owned by CAP, is an example of integration between operational and quality data with the territory characteristics in a GIS application. During DWC project, the actual WebGIS will be upgraded, and the Digital Solution 4 will be developed, in order to create a WebGIS platform for improved decision making in water reuse[1].

In the case of water reuse for agriculture, the quality of the reused wastewater effluent can change during its permanence in storage tanks or due to the conditions of the irrigation pipes. Finally, additional technical aspects, such as the choice of the irrigation technique, the crop selection, and the practices of harvesting, washing or processing products, require specific attention on health-risks evaluation. For those reasons, when facing health risk management, the monitoring of wastewater quality should be extended to the whole utilization cycle of water, in order to take into account all the critical points that may influence the health risk assessment. For this purpose, this work proposes a superstructure that covers all the urban wastewater cycle, from catchment to agricultural field.

The superstructure considered is the Integrated Wastewater and Reuse System (IWRS), which schematizes the wastewater cycle in an urban area, and includes five main components: catchment, sewer network, wastewater treatment plant, irrigation system, and irrigated field.

Below is reported a description of each component of the IWRS. Boundaries and interconnections between the different components and data required for water reuse monitoring/modelling that can be found in the WebGIS platform are described as well.

1.1 Background

First of all, it is necessary to define objectives and identify the system to be analysed and its boundaries. General information that contextualizes the IWRS in site-specific conditions and geopolitical background relies on:

- legislative framework, health-based target, regulatory limit values, quality standards, certification and auditing requirements;
- demographics and land use data, geographic location, climate conditions;
- design parameters and management information.

The system boundaries must be defined, together with its geographical and geopolitical context, since these aspects can affect regulatory quality requirements and the possible final reuse applications. The choice of the intended reuse application, especially in case of planning activities or project design, should consider policy restriction, surrounding land use and environmental impacts, other than economic and social evaluations.

[1] https://www.digital-water.city/solution/webgis-platform-for-improved-decision-making-in-water-reuse/

In Peschiera Borromeo IWRS context, the main regulatory framework to take into account is the Italian regulation on water reuse DM 185/2003, as well as European Regulation 741/2020. Neverthless, the actual regulation on wastewater discharge D.Lgs 152/2006 needs to be considered, since in case of non-compliance for water reuse, quality for discharge must be anyway guaranteed.

The geographical context of Peschiera Borromeo IWRS is the peri-urban area of Milan. Agricultural activities, as potential users, must be considered, together with the cultivated crops, the related water needs, the typical irrigation methods and climate conditions.

1.2 Catchment

Catchment area influences both quantity and quality of wastewater depending on the population served, the number and type of commercial and industrial activities located in the area, and, in case of combined sewer, the land morphology and climate conditions. Thus, data required for catchment basin characterization includes served population, specific water supply, percentage and type of industrial discharges, catchment extension, land topography and morphology, land use, rainwater runoff. Population served and specific water supply provide information about the average flow rate of the wastewater influent that needs to be treated at the WWTP, and that could be potentially reused for agricultural purposes. In particular, tourist fluxes in the area can cause seasonal variability on wastewater flow rates. In addition, information about presence and type of industrial activities are useful to characterize wastewater quality. Moreover, the presence of specific activities in the area can suggest the presence of some chemical contaminants or expected seasonal variations in loads, such as in the case of agro-industrial factories. Finally, historical data related to rainfall, their seasonal variability and the frequency of extreme events can be obtained from National or Regional authorities (ARPA). All those data can be managed by a GIS platform, which enable the integration of a visual representation of the physical catchment area with all data related to the characterization of the different sources of wastewater fluxes.

The catchment of Peschiera Borromeo WWTP is located in Milan peri-urban area and is divided into two areas: one is served by the conventional line of the plant (Line 1) and includes the peri-urban area of Milan and the municipalities of Brugherio, Carugate, Cassina de' Pecchi, Cernusco sul Naviglio, Cologno Monzese, Peschiera Borromeo, Pioltello, Segrate, Vimodrone; instead, the East districts of Milan are served by the Line 2 of the plant.

The contribution of industrial sewage is estimated to be approximately 23%. Specific laboratory analyses are performed periodically on the industrial fluxes, to: (i) quantify the total amount of industrial wastewater produced, (ii) quantify industrial contaminants load, and (iii) verify the compliance with the limits established in the Table 3, Annex 5 of D.Lgs n. 152/2006, which regulates wastewater discharges.

The GIS platform WebGIS Acque di Lombardia, managed by CAP Holding, includes the representation of the catchment served by Peschiera Borromeo (Figure 1), and stores information on produced wastewater fluxes. The WebGIS will be optimized to improve the management of all the peri-urban area of Milan, evaluating the feasibility of wastewater reuse practices in the territory. This will enhance the replicability of the project results.

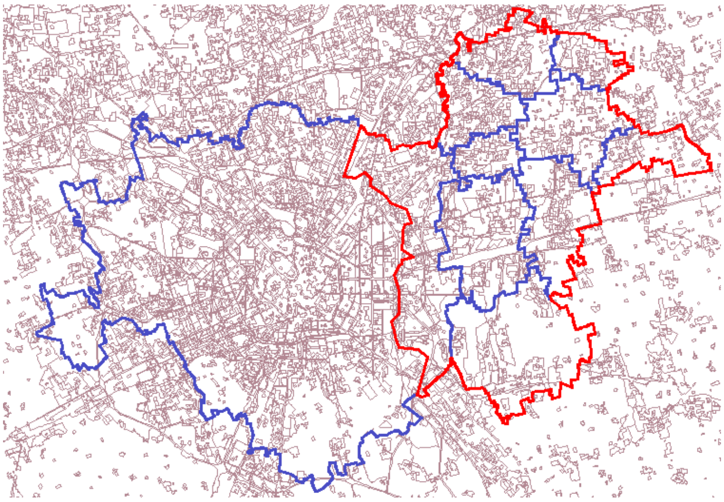

Figure 1: Peschiera Borromeo catchment area (in blue) and boundaries of served Municipalities (in red)

1.3 Sewer network

Sewer network collects wastewater and conveys it to the WWTP. Sewers with separated pipelines or mixed with stormwater influence the amount and quality of wastewater to be treated at the receiving WWTP. Sewer network can be also characterised by the presence of pits, pumping station, storage tanks and combined sewer overflows (CSOs). Length, slope and diameter of pipelines can influence phenomena of solid settling, which may be reason of imbalances on the ratio between particulate and dissolved matter, and consequently on the microbial load attached to solids. In addition, hydraulic information on flow rates and their daily variations, chemical and physical characterization of sewage and rainwater runoff can be collected by a GIS platform.

The sewer network that collects urban wastewater to Peschiera Borromeo WWTP is divided in two sectors, which serve separated areas of the Peschiera Borromeo catchment and are managed by different utilities. One sector is controlled by Metropolitana Milanese and collects sewage flows from the municipalities of Brugherio, Carugate, Cassina de' Pecchi, Cernusco sul Naviglio, Cologno Monzese, Peschiera Borromeo, Pioltello, Segrate e Vimodrone. The second sector is directly managed by CAP Holding and serves the municipality of Milan and the district of Linate. In the sewer network controlled by CAP, stormwater overflows are managed using 8 equalization ponds, controlled and activated remotely (Figure 2). The remote control is based on the measurements of sensors for tank level and rainfall measurements.

Particularly, parameters visualized and/or controlled in remote mode are:

- Pumping status
- Influent and effluent flow rates
- Tank level
- Rain sensor

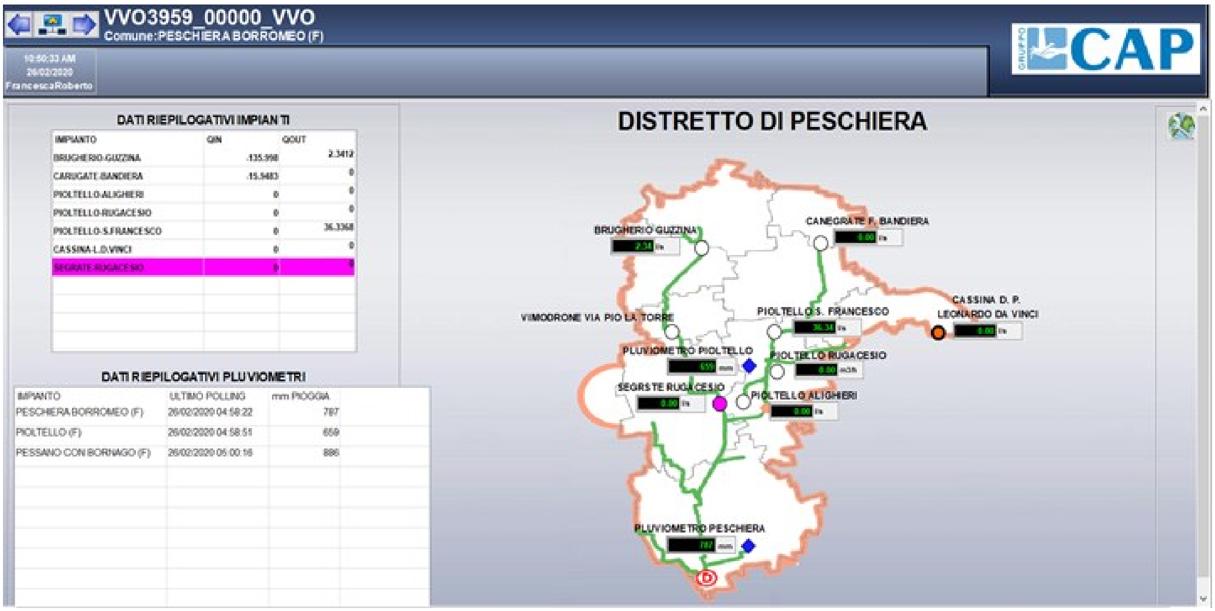

Figure 2: Remote equalization tanks control

1.4 Wastewater Treatment Plant

WWTP layout is made up by different processes that take place in different operative units and can be schematized as a sequence of treatment stages. Peschiera Borromeo WWTP is located in the peri-urban area of Milan, in Via Roma - Cascina Brusada. It has a treatment capacity of about 566000 PE, and treats daily an average flow rate of 216000 m^3. The plant has two separated treatments trains (i.e., Line 1 and Line 2), which treat the wastewater coming from the two sewer network sectors of the peri-urban region of Milan. Sewages coming from the area managed by Metropolitana Milanese are treated in Line 1, whereas the wastewater coming from the sewer sector controlled by CAP is treated in Line 2. Line 1 includes coarse screening, pumping station, fine screening, grit and oil removal, primary sedimentation, biological treatment for organic carbon removal, tertiary filtration combined with nutrient removal in BIOFOR reactor and chemical disinfection with peracetic acid. Line 2 includes coarse screening, pumping station, fine screening, a compact SEDIPAC unit for grit and oil removal coupled with primary sedimentation, a BIOFOR unit for organic and nutrient loads removal combined with tertiary filtration and a final disinfection treatment with UV.

Peschiera Borromeo WWTP is equipped with a monitoring network of conventional sensors to verify effluent quality, in terms of NH_4, N-NO_3, PO_4 and TSS. Probes for the measurement of REDOX, Dissolved Oxygen, Temperature and N-NO_3, are installed in the biological unit. During DWC project, the plant was equipped with UV, TOC, pH and Conductivity sensors to monitor effluent quality, as well as new sensors of NH_4, PO_4, TSS, pH and Conductivity for the influent.

1.5 Irrigation system

Irrigation system defines methods and related equipment used to store, transport and distribute the treated effluent from the WWTP to its final application in the agriculture land. Two different levels of influence are considered, namely consortium level and farm level, as they involve different actors and related responsibilities.

1.5.1 Irrigation at consortium level

Consortia that manage irrigation water are responsible for the pipelines and the storage systems used to collect and transport the treated water to the final users. Storage tanks represent potential causes of pathogen regrowth, whereas problems of solid sedimentation, leakage or intrusion may happen along the pipeline. Stakeholders involved in the consortium are responsible for the management of tanks and pipelines.

The geographical context of Peschiera Borromeo WWTP is the Lombardy Padana Plain. Agriculture is a crucial sector for the economy of the region; activities are mainly related to fodder crops, such as maize. The most common irrigation techniques rely on border irrigation, implying a water demand of about 3000-4500 m^3/(ha*month) during the irrigation season. The current water source comes from rivers, and it is distributed by gravity through a network of open unlined canals and irrigation water is supplied to farmers under rotation. The irrigation network of canals and the related water delivery systems are managed by the consortium Est Ticino Villoresi, which is one of the most important irrigation consortia in Italy.

1.5.2 Irrigation at farm level

Irrigation at farm level is under farmers' responsibility. It is mainly related to the technology used to irrigate crops by reclaimed wastewater. According to the "Regulation (EU) 2020/741 of the European Parliament and of the Council on minimum requirements for water reuse", different limits on water quality can be applied, depending on the method used to irrigate crops. Furthermore, the use of some irrigation techniques may require special attention to the health of workers, bystanders or people in the nearby community.

For the assessment of the effects of the use of different irrigation techniques, the experimental field investigated during DWC project was divided into two parts of 625 m^2 each, which will be irrigated by border and drip methods, respectively. Border irrigation is representative of common agricultural practices in the area, while drip irrigation is an innovative smart practice, which can be introduced at the same time as the digital solutions. Drip irrigation can provide a timely and precise supply of water and nutrients to the crop, according to the indications provided by the match-making platform (https://www.digital-water.city/solution/match-making-tool-between-water-demand-for-irrigation-and-safe-water-availability/). Sub-surface drip irrigation was also considered as a valid alternative option, since it implies significant advantages, such as the elimination of contacts between water and the epigeal part of the plant, minimizing contamination risks from pathogens. Considering the soil characteristics of the experimental field, it was decided to adopt drip irrigation as an alternative method, at least for the first year, with the possibility to shift to sub-surface drip irrigation in a second period. The final choice will be based on the preliminary results of the monitoring campaigns.

1.6 Irrigated soil and crop

Soil characteristics influence the kinds of crops that can be cultivated and their water requirement, as well as the position of the irrigation area influences the exposure to health risks for local communities living nearby the irrigated field. Soil and groundwater pollution should be also considered during risk assessment, whereas crop quality determines both quantity and quality of irrigation water: different kinds of crops need different amounts of water. Furthermore, the amount of water for irrigation and the frequencies of the irrigation events are different during the different periods of the year. Crop quality involves also different risk considerations, which depend on harvesting practices, treatments accomplished to obtain the final product, and the final use of the product itself (e.g., consumed cooked or raw by humans or animals).

The experimental fields selected in this project have been cultivated with maize and standard agricultural practices were applied. The reclaimed water for irrigation will come from Line 2 of Peschiera Borromeo WWTP. The experimental plot to test the agricultural water reuse is located beside the Peschiera Borromeo WWTP, and it is characterized by an extension of 1250 m^2 (25 m x 50 m, corresponding to 0.125 ha). A preliminary phase of soil characterization was performed before the construction of the embankment. Soil surveys at six points and one depth (from 20 to 40 cm), and geognostic investigations using the Geonics electromagnetometer profiler to explore greater depths were carried out. Results from soil surveys showed a texture of sandy loam almost homogeneous, with no significant differences between the different sampling points. The electromagnetometer provided electrical conductivity maps (in mS/m) at different depths following the frequency settings. The electrical conductivity can be correlated with soil water content as well as the capacity of the soil to retain or drain water. The conductivity maps identified quite homogeneous soil characteristics in all explored horizons (from 5 cm to 6 m), except for a small central portion of the plot (about 10 m^2), where the soil appears more retentive.

Data from pluviometry stations distributed along the catchment will be acquired, together with online measurements accomplished at the WWTP, which are related to the quantity and the quality of water available for agricultural reuse.

In Table 1 are reported online measurements that will be collected at the experimental irrigation fields.

Table 1: AG online data

Variable	Scale	Provider
Rainfall	Field / Area (order of km^2)	API linked to Weather stations API from weather services
Wind Speed & Direction		
Air Temperature & Humidity		
Solar Radiation		
Soil Volumetric Water Content	Field	API linked to sensors on the field
Soil Temperature		
Water Stress Index	Field (using UAV) / Area using satellites	Drone Satellite (e.g. Sentinel-hub)

A match making tool between water demand for irrigation and safe water availability will be developed as Digital Solution 5b, in order to connect WWTP with final users. Moreover, the Digital Solution 5a will also be developed during the project and will consist of an active unmanned aerial vehicle for analysis of irrigation efficiency. Data from satellite images will be also used.

2 WebGIS Acque di Lombardia

G.I.S. is a Geographic Information System. Between the many definitions, we report the following as closer to the general description of information system: "A geographic information system is a system composed of databases, hardware, software and organization that manages, processes and integrates information on a spatial or geographical basis", Barrett-Rumor 1993.

In a nutshell, WebGIS can be defined as a GIS published on the web. While GIS applications are created and developed to manage spatial information on a desktop environment, allowing the consultation on a single workstation, WebGIS is the extension to the web of those applications. Thus, the main differences between a WebGIS project and a GIS project are communication purposes and information sharing.

WebGIS has taken on an increasing level of strategic importance and is developed in the phases of organization and management of spatial data, as well as to foster interaction and cooperation between public and private bodies, bring citizens closer to institutions, limit response times and qualify the services offered.

WebGIS offers a variety of advantages, the most relevant are listed as follows:

- In terms of access and dissemination, this system is published on the Internet and can be reached and consulted quickly from any part of the world even by mobile devices.
- The cost of access for end-users is low, as in consulting the WebGIS system and cartography users have to bear only the costs of internet connection: hence, it is not necessary to acquire expensive cartographic management software.
- Transparent access: WebGIS, through the publication on the web of thematics, allows an extreme simplification in their reading and analysis by end-users, who do not have to be specialized: in other words, the system is accessible to various users and not only a few technicians.
- Communication, sharing, transparency and participation: these are the guidelines of the public administration, allowing people to fully understand the decisions taken, highlighting the coincidence between objectives pursued and use of the power conferred by law.

The water and sewerage network map of over 1,000 municipalities in Lombardy is online thanks to the new WebGIS Acque di Lombardia, the platform is dedicated to the wealth of data and information of many managers of the integrated water service in Lombardy, being part of Water Alliance. CAP is the owner of the system, managing technical aspects and coordinating other utilities of Water Alliance, each of them has an office dedicated to data handling for the specific competence area.

"Water Alliance - Acque di Lombardia" is the first network of companies between water utilities (in house) of Lombardy Region. It includes CAP Holding, Brianzacque, Uniacque, Padania Acque, Lario Reti Holding, SAL, Pavia Acque, Acque Bresciane, Alfa: nine public companies of the integrated water service that together guarantee a quality service to over 5 million inhabitants (more than half of the citizens of Lombardy) and who have decided to team up to combine local roots and best practices in public water management. The project is sponsored by ANCI Lombardia and Confservizi Lombardia.

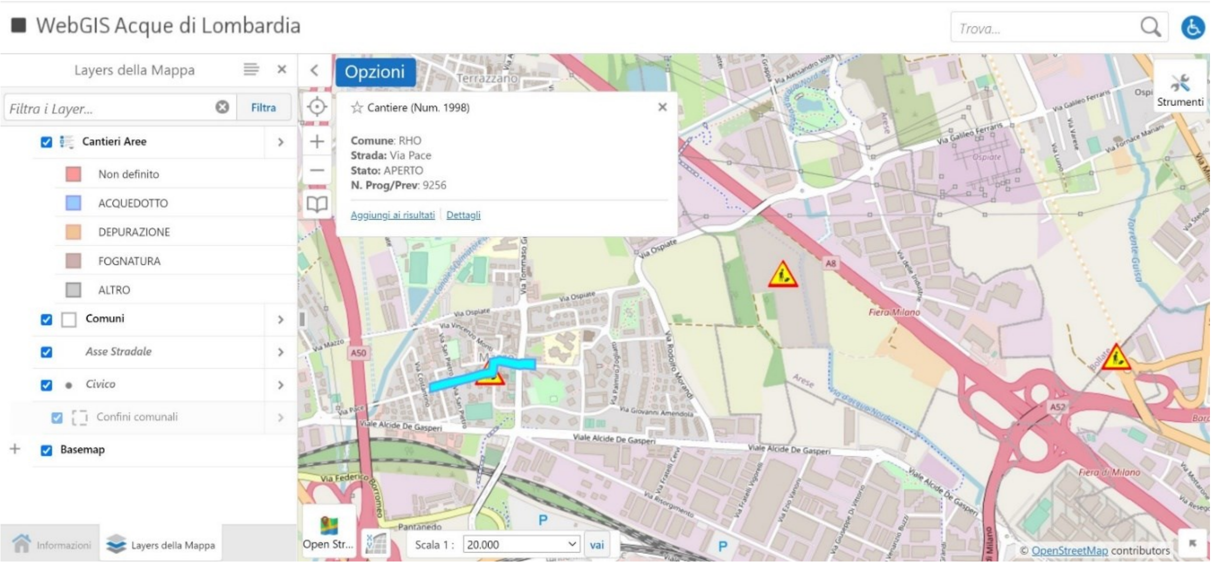

Figure 3: Overview of WebGIS Acque di Lombardia

WebGIS Acque di Lombardia has been developed for the first time by CAP in 2012. Over the years, the project has expanded: Brianzacque (Monza and Brianza), Uniacque (Bergamo), Lario Reti Holding (Lecco), SAL (Lodi) have joined the project and recently four public companies came aboard: Pavia Acque, Padania Acque (Cremona), Acque Bresciane, Alfa Varese.

This WebGIS is the result of a remarkable synergy between the water utilities of Lombardy to provide a single reference for water related cartographic information to technicians, municipalities, and professionals (members of Orders of Engineers and Architects, technical offices of the managed Municipalities and external companies working on the utility infrastructures). The introduction of the WebGIS in water cycle management allows having a detailed view of structures and infrastructures on the territory, representing a centralized system to chart information about their near real-time conditions. In particular, through WebGIS, all the information about works and interventions on the networks or plants can be digitally consulted by all the actors potentially interested.

Born from the union of GIS (Geographic Information System) and the interactivity of the web, WebGIS Acque di Lombardia is a system that, through simple and intuitive interfaces, provides a real-time update of all facilities related to the integrated water service and gives access to all users, such as managers, professionals, municipal technicians, who can interact with the managers of the integrated water service through a single platform.

WebGIS can capture, extract, and manage assorted information derived from geo-referenced data, and make it available remotely. The platform employs a team of 40 people from the 9 companies and manages an impressive amount of data relating to over 70 thousand km of network of aqueduct and sewage, bound to grow further over the years. Within this arrangement, the system has arrived to map two-thirds of the territory of the Lombardy Region, for a total of 1,050 municipalities.

Figure 4: Detailed view of WebGis Acque di Lombardia

The System Project features a geographic DB maintenance environment (Desktop) and a reference environment (WebGIS and Mobile).

The project has a set of ArcGIS desktop stations (GEONIS), for the management of a database related to networks and infrastructures of the integrated water service for all companies that are part of the project.

The system enables the daily management of network paths and the management and maintenance of networks by the technicians of the various companies. Data are structured on a multi-user Oracle RDBMS that discloses information about the water service network transparently and effectively and acquires, extracts and manages the extensive information deriving from geo-referenced data. The desktop maintenance platform of the geographic DB provides access for profiled users only and, depending on the operator belonging to the user, the objects of competence are accessible for reading or writing.

The WebGIS component, based on ESRI and GEOCORTEX platform, offers consultation, research and analysis of geo-referenced data and is aimed not only at users of the Network Managers but also at an external public (Authorities, Administrations, professionals, etc.) using a user profiling system that automates the visibility of content and functionality for each account.

Data consultation takes place through the Web Application "Geocortex HTML5 Viewer", an evolved WebGIS viewer that natively presents many typical features of GIS Desktop applications: graphic editing including multi-layer snapping, customization of the legend, graphics, SQL query builders, saving and interacting print search formats up to A0, saving projects, geographic chat ("Collaboration"), integration with Street View, compatibility with WCAG regulations. The Web Application can be used with any browser (provided HTML5 supports), on any device and with any operating system and is completely responsive.

In addition to native Geocortex functionalities, vertical functionalities have been implemented for the automation of research and analysis tools, as well as integration with other systems:

- Guided Research: developed for: Roadway, Cadastral Land, Annotations, Maintenance interventions, Construction sites, As-Built, Opinions and Tests, Interference, Industrial Practices, Critical' Sewage, Nemo (maintenance of networks), Video Inspections, Leak Search. In addition, the search parameters are filtered according to the user profile, so that only values compatible with the operator are presented.
- Vertical Functionalities. Features of geographic data maintenance and analysis reserved for authorized users have been developed.
- Tracing Aqueduct: analysis of service interruptions
- Tracing Sewage: analysis of the origin of water
- Longitudinal Profile: Sewer System Profile
- Net Districts: analysis of the consistency of the water net subdivided in Districts
- PGT consultation: integration with PGT tables published by an external service
- Geology Portal: integration with the Geology Portal
- Loading Interventions: insertion, modification and elimination of Interventions
- User Annotation Management: Insertion, Modification and Deletion of User Annotations
- As-Built management: insertion, modification and deletion of As-Built
- Site management: insertion, modification and elimination of Sites
- Management of Opinions and Tests: insertion, modification and elimination of Opinions and Tests
- Interference Management: insertion, modification and elimination of Interference
- Management of Industrial Practices: insertion, modification and elimination of Industrial Practices
- Criticality of Sewerage: insertion, modification and elimination of "critical element" on the the sewer network that are part of the annual Critical Points Plan, identified each year and classified according to the degree of criticality (high, medium, low), by the Sewage Management Sector;
- Monograph Generator: production of PDF monographs of the network structure
- Loading Video inspections: insertion, modification and deletion of Video inspections
- Loss Loading: Insertion, Modification and Elimination of Losses
- Layers Catalog: to add additional layers to the map organized in a Catalog
- Sites Public Portal: a Public Portal has been created for the consultation of the Site Map that exposes the contents and functionalities of public domain.

There is also dedicated access to municipalities and professionals whose order has signed an agreement with the related manager.

The application of a WebGIS can be extended to any subject related to territorial information. The analysis of phenomena on the territory can highlight a spatial correlation between them and identify causally related events, that would not be evident otherwise: health and environment, network inefficiencies and network features, social variables and urban planning, explanation of behaviors and social reality. This project employs these relational potentials of GIS, which makes it a decision support tool (DSS).

2.1 General Structure and Layouts included

The structure of the system includes architecture, software application and Database Management System.

With respect to the architecture of the system, the infrastructure provides 3 basic environments: Production, Pre-production-Test-Testing and Development.

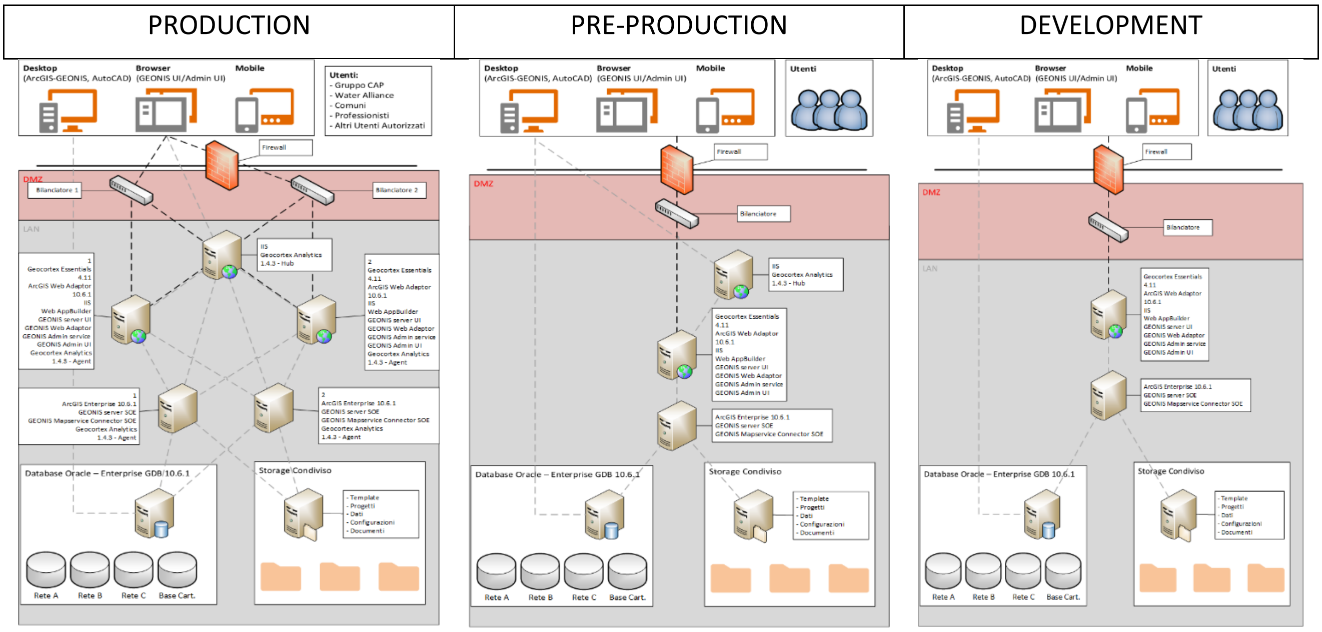

Figure 5: Environments of WebGIS infrastructure

The production environment is intended to supply services to final users.

The Pre-production-Test-Testing environment is intended for the verification of services coming from the Development environment and intended for Production.

The Development environment is intended for procedures realization and software and design updates, which will then be first released in the environment of Pre-production-Test-Testing and in the production environment, after verification.

In terms of Software, the project is developed using the latest versions of the Server of the Esri ArcGIS suite and the Geocortex Essentials platform and allows the most extensive expandability and integration with other databases and other possible features.

WebGIS is based on a data model commonly used in Europe for the description of aqueduct and sewerage networks: in fact, it has been adapted to the project and the needs of the operators. The data model represents the scheme of main elements required for database description: the technologic network is conceptually modelled using entities and relations between them.

The data model integrates the Databases related to the different technological networks and territorial areas of the Managing Authorities and each Managing Body can consult only the data relating to its territory through a system of territorial and user profiling.

2.2 Characteristics displayed in the current GIS

In the next paragraph, the main features of the current WebGIS are described. The Framework Web is Geocortex by VertiGIS, whose main advantages are:

- Design framework to realize projects that prioritize the application configuration to the development of source code, reducing time of realization and ensuring durability of the applications
- Integration with ArcGIS Enterprise platform, both for the ArcGIS Server component and the Portal component
- Support for Web viewers in HTML5 and Responsive format and with advanced project management
- Support for native Mobile application, for Android, iOS and Windows environments
- Dedicated reporting and printing environment
- Visual development environment for customizations (Workflow Designer)
- Possibility to create print and customize modules that can be shared with the native mapping environment of ArcGIS Portal
- Integration with Data Connection

Geocortex Essentials (Figure 6) is a unique product because it covers the gap between ready-to-use (off-the-shelf) pre-packaged software and the development of traditional applications. Geocortex Essentials provides a set of development tools, key software components, and features universally required by organizations to meet their needs in implementing web-based mapping applications. In addition, Geocortex Essentials allows you to easily configure applications through visual administration tools (workflow), which significantly reduce the need for programming.

Figure 6: Geocortex Essentials capabilities

Geocortex Essentials features are provided through a framework-based design that includes a variety of built-in predefined components, an underlying data model, as well as infrastructure and development tools. There are many advantages to adopting framework-based software design, such as increased productivity, more reliable applications, and shorter cycle times for implementations.

Geocortex viewers offer advanced characteristics: they provide simple and targeted mapping applications across desktop browsers, tablets, and a wide range of handheld devices. They are fully integrated with other highly configurable Geocortex Essentials components and use Web administration tools to facilitate development, customization and updates.

For mobile users, Geocortex viewers can work offline. Access to basic maps while working offline is also possible on mobile devices (available on iOS, Android and Windows) using a Geocortex App.

It is possible to log in to the WebGIS application from the gallery, in which the list of web applications or sites appears.

The following sites are currently available:

- Aqueduct site (Acquedotto): to access the map with ACQ network
- Sewage Site (Fognatura): to access the map with the SEW network
- Aqueduct and Sewage site: to access the map with both ACQ and FOG
- Textbooks (Manuali): to access video tutorials

Each user is associated with a functional role. According to its role, the user can access several contents and functionalities.

The interface includes different sections:

- an upper bar;
- a panel on the left;
- a central box where there is a map with some other tools;
- an Options menu;
- a Tools menu.

The main components of WebGIS Acque di Lombardia is shown in Figure 7:

1. Button for easy access, to activate specific functionalities related to the use according to international legislation WCAG 2.0.
2. On the left there is a panel where the data levels are displayed, the results and the functionalities.
3. While using, two or more tabs may appear at the bottom.
4. The button on the top left is to find the current location, the map is then located on the coordinates of the user. This feature is very useful if the user is on the field and is using a tablet or mobile phone.
5. The map is the central part of the interface and has predefined display scales. A range of information and different features can be seen by clicking the right mouse button on the map.
6. Options menu, to access a set of predefined functionalities.
7. In the Tools menu, there are vertical functionalities realized for the project.

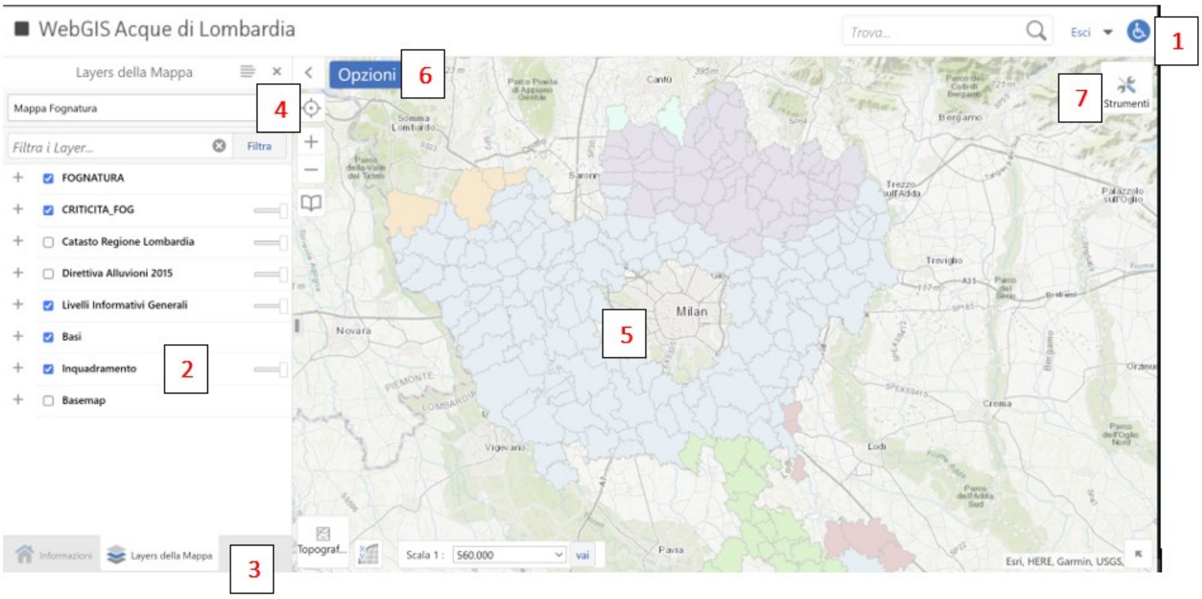

Figure 7: Main components of WebGIS Acque di Lombardia

The sections *Search* (*Ricerche)* and *Functions (Funzioni)* are available from the left. They are custom searches and features for the Webgis Acque di Lombardia project, as shown in Figure 8.

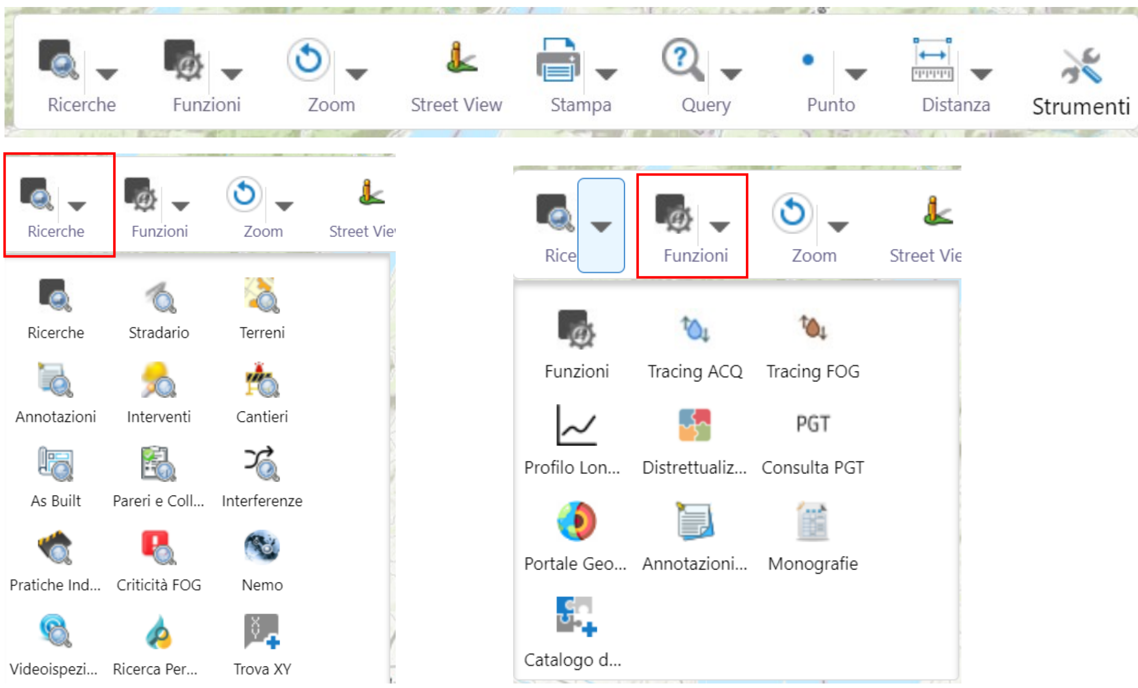

Figure 8: Search sections of WebGIS Acque di Lombardia

With *Street View*, it is possible to use the service within the WebGIS MAP, while with the Print button multiple options are available, such as to print in various formats from A0 to A4.

The button Q*uery* enables selection tools to identify specific data on the map. Among others, *Query builder* can show on the map what corresponds to certain conditions and parameters and *Filter (Filtro)* can switch off, on the map, everything that does not correspond to a set SQL query.

The contents of the map can be shown by selecting the tab “map layers”. At the top there is a list of default maps, which are an automatic composition of layers in the map. The list of layers and its aspect change by enabling a different map.

Layers that can be visualized on the map are as follows:

- *Aqueduct (Acquedotto)*: within this group there are the sub-levels of the aqueduct network exercise, WSP Water safety plan.
- *Sewerage (Fognatura)*: within this group there are the sub-levels of the operating sewerage system and critical sewerage
- *Land registry of Lombardy Region (Catasto Regione Lombardia)*: it is a web service provided by the Lombardy Region that allows access to cadastral maps
- *General information levels (Livelli Informativi generali)*: it contains topographical database, namely road map, civic numbers, constraints, interferences
- *Framework (Inquadramento)*: in the frame group all the municipalities of the managers that are part of the project Acque di Lombardia are displayed.
- *Basemap*: to access topographic, satellite, political, physical maps of the territory.

WebGIS also includes many vertical features, allowing operators to carry out their activities. Some examples of the features accessible to all the users are listed below:

- Annotation form: thanks to this function, users can insert annotations, such as notes and reports, through punctual/linear/areal elements, directly in the cartography of the WebGIS and it is possible to share in real-time the findings obtained from surveys in situ or inferred from other sources; annotations must subsequently be analyzed, processed and validated by the GIS office of territorial competence that will provide, if necessary, the cartographic update.
- “Portale Geologia”: the Geology portal is a web application integrated into the company’s WEBGIS, based on an ESRI platform and configured to provide specific geological functionalities. The Geology Portal helps to enhance the vast cartographic heritage of the Geology Sector using guided tools that make it easy for the user to refer to the map (also in a temporal manner).
- Districts: The district function enables, on the WebGIS side, to display information, divided on a municipal basis, concerning the division into districts of the water distribution network. Districts related information can be entered into the system directly by members of the GIS office, based on hydraulic district and leak research studies elaborated by relevant offices.
- PGT (Piano di Governo del Territorio - Territorial Governance Plan) consultation: Through this function, it is possible to upload and visualize cartographic data available at https://www.pim.mi.it/pgtonline (cartographic services portal PGT Online - Città Metropolitana di Milano, realized by Centro Studi PIM, that allows the online consultation of the cartographic drawings of the georeferenced PGT of the Municipalities of the Metropolitan City of Milan).
- Monographs: By selecting a point on the sewer map you can dynamically create a real-time monograph with the data present in the system at that time.

2.3 A new site of WebGIS for the water reuse

A new module within WebGIS Acque di Lombardia is implemented in order to obtain a new tool for the management of treated water reuse and associated risk for environment and human health.

Figure 9 shows a schematic diagram of the whole data integration, including quality classification, specific parameters of water from WWTP and the relationship between these characteristics and the agricultural uses according to "Regulation (EU) 2020/741 of the European Parliament and of the Council on minimum requirements for water reuse". Additionally, in more advanced versions of the site, information about water characterization and cultivated crop will be used for introducing Quantitative Microbial Risk Assessment (QMRA) and Quantitative Chemical Risk Assessment (QCRA), thus evaluating the toxicity for humans and plants related to water reuse.

Finally, a possible integration with early warning signals obtained with Artificial Neural Network (ANN) is analysed.

Blue blocks in Figure 9 indicate the current sites of WebGIS Acque di Lombardia, whereas the new implementation is represented in orange.

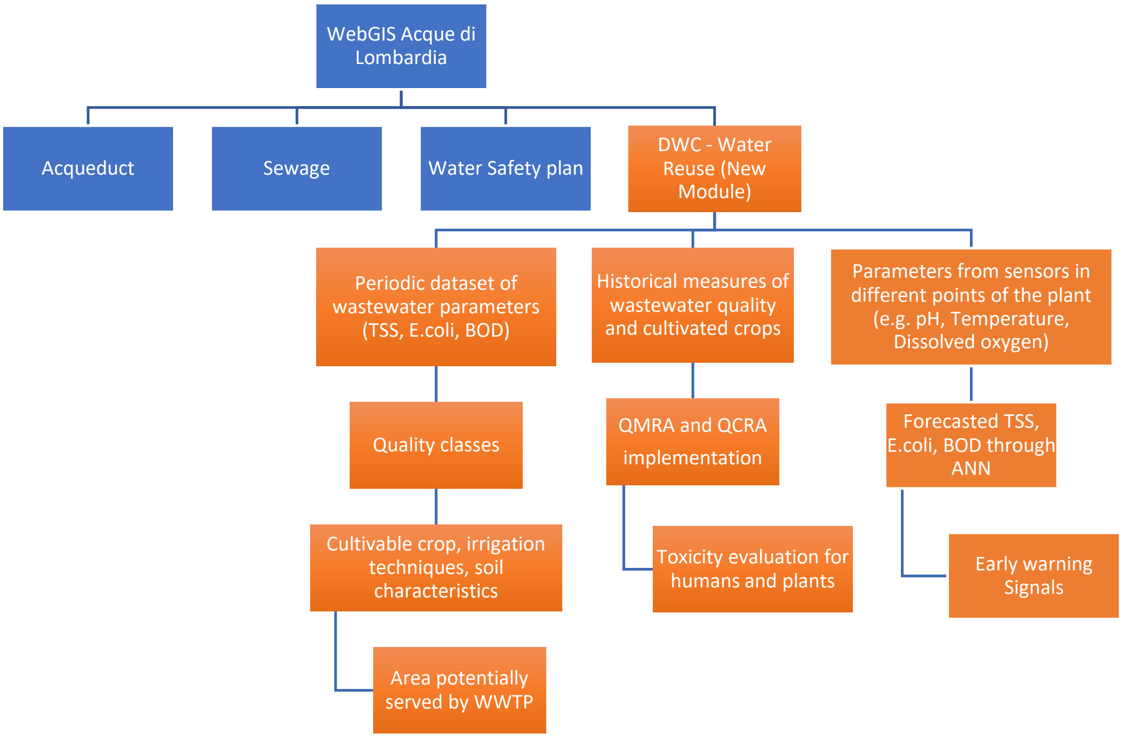

Figure 9: Schematic diagram of WebGIS system Architecture

The new site contains also some of the layers included in other sections of the system, previously described, such as:

- Cadastral maps
- Roads
- Municipalities
- Water bodies
- Aqueduct: main networks, treatment plant
- Sewarage: main networks, WWTP

Furthermore, some information from Geology Portal about groundwater and geomorphology are added in order to give a complete overview of the water resource:

- Soil typology
- Piezometry
- Hydrological parameters
- Meteorological overview
- Hydro-chemical parameters
- Geotechnical parameters

An overview of the new homepage is reported in Figure 10, including an initial description of the DWC project. Following sections present a detailed view of the main elements and data integrated in the new WebGIS architecture.

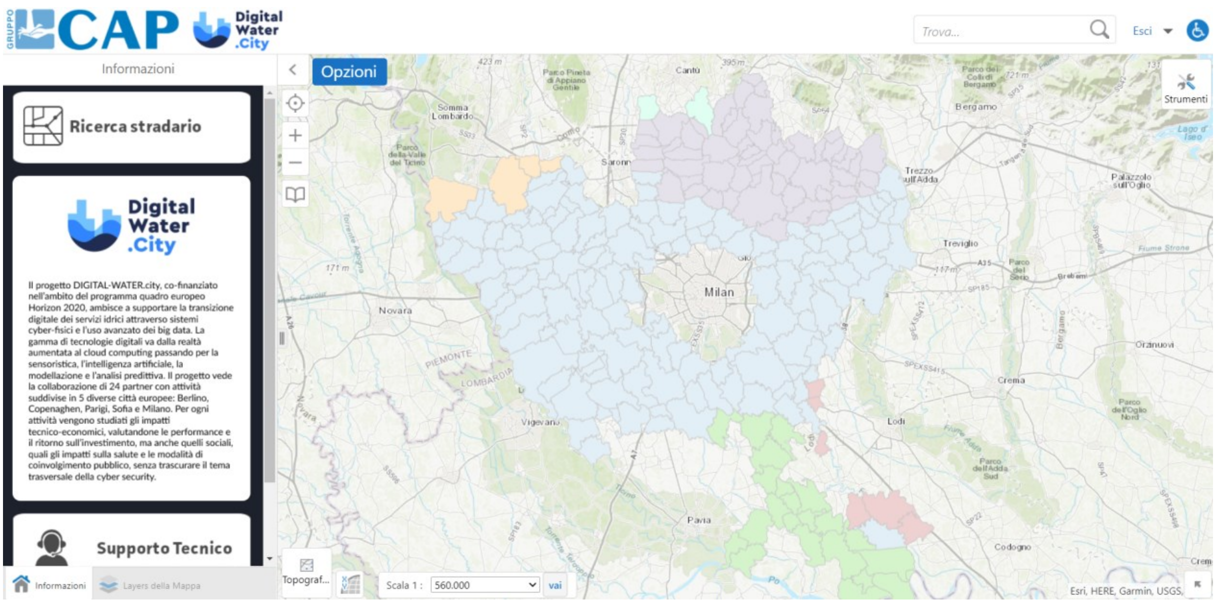

Figure 10: DWC site of WebGIS (The image represents only a draft of the site, then subject to amendment to the final output)

3 Agricultural reuse of treated water from WWTPs

According to DWC goals, some new layers related to agricultural reuse of water have been implemented:

- A layer includes the WWTP available for water reuse, reporting some information about the water flow and the main parameters to take into account for a proper characterization of water intended for water reuse.
- A layer focuses on the purple district of Peschiera Borromeo plant, reporting the area potentially served by the WWTP (see Section 4).

3.1 WWTP potentially available for water reuse: water characterization

As mentioned before, the "Regulation (EU) 2020/741 of the European Parliament and of the Council on minimum requirements for water reuse" states that limits on water quality depend on the method used to irrigate crops and irrigation techniques, with special attention to the health of consumers, workers, bystanders or people in the nearby community (Table 2 and Table 3).

Table 2: Classes of reclaimed water quality and permitted agricultural use and irrigation method according to the "Regulation (EU) 2020/741 of the European parliament and of the Council on minimum requirements for water reuse" (EU Regulation, 2020)

Minimum reclaimed water quality class	Crop category (*)	Irrigation method
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation (**) or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods (***)

(*) If the same type of irrigated crop falls under multiple categories of Table 1, the requirements of the most stringent category shall apply.

(**) Drip irrigation (also called trickle irrigation) is a micro-irrigation system capable of delivering water drops or tiny streams to the plants and involves dripping water onto the soil or directly under its surface at very low rates (2–20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers.

(***) In the case of irrigation methods which imitate rain, special attention should be paid to the protection of the health of workers or bystanders. For this purpose, appropriate preventive measures shall be applied.

Table 3: Reclaimed water quality requirements for agricultural irrigation according to the "Regulation (EU) 2020/741 of the European parliament and of the Council on minimum requirements for water reuse" (EU Regulation, 2020)

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (number/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	*Legionella* spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	-	
C	Secondary treatment, and disinfection	≤ 1 000			-	
D	Secondary treatment, and disinfection	≤ 10 000			-	

With the aim of defining a layer that identifies the WWTP that are potentially available for reclaimed water reuse in agriculture, data from the fifteen largest plants managed by CAP have been analysed.

Starting from the data measured through laboratory tests during 2020, parameters reported in Table 3 have been evaluated, focusing on values of BOD5 (Biochemical Oxygen Demand), TSS (Total Suspended Solids) and *Escherichia Coli*.

Collecting the data measured in each plant, the four classes have been defined setting limit values of these parameters, as reported in Table 4.

Table 4: Quality classification for reclaimed water

Quality class	BOD [mg/l]	SST [mg/l]	E coli [UFC/100ml]
A	≤10	≤10	≤10
B	≤25	≤35	≤100
C	≤25	≤35	≤1000
D	≤25	≤35	≤10000
NO Reuse	>25	>35	>10000

Each day of analysis has been associated to a class, basing on the mentioned values.

In such a way it was possible to compute the percentage of times in which the water from a specific plant has been in the different classes as:

$$\%Class\ \boldsymbol{X} = \frac{number\ of\ test\ days\ in\ Class\ \boldsymbol{X}}{number\ of\ total\ test\ days}$$

The resulting data are reported in Table 5 for the fifteen plants analysed.

Table 5: Water quality classification for selected WWTP

Plant	Class A	Class B	Class C	Class D	No reuse
Abbiategrasso	63%	33%	0%	4%	0%
Peschiera Borromeo - Linea Nuova	54%	40%	6%	0%	0%
Rozzano	93%	4%	4%	0%	0%
Assago	93%	4%	4%	0%	0%
Truccazzano	33%	54%	6%	8%	0%
San Giuliano Est	55%	37%	2%	6%	0%
Bresso	54%	22%	14%	8%	2%
Trezzano Sul Naviglio	92%	4%	2%	2%	0%
Pero	30%	26%	20%	18%	6%
Cassano D'adda	59%	33%	4%	4%	0%
Canegrate	94%	4%	2%	0%	0%
Locate Di Triulzi	24%	20%	31%	24%	0%
Robecco Sul Naviglio	46%	35%	19%	0%	0%
Settala	41%	49%	8%	2%	0%
Peschiera Borromeo - Linea Vecchia	29%	48%	19%	4%	0%

3.2 Areas potentially served by WWTP and cultivable crop depending on water class quality and irrigation infrastructure available

Although, in the area surrounding the city of Milan, freshwater for irrigation is still relatively abundant, climate change and the increasing competition emerging among alternative water uses represent serious threats going forwards. In addition, in the areas enclosed within the urban development, the traditional agricultural practices are hardly sustainable, and the so-called peri-urban agriculture urgently needs to be promoted.

In such a context, the implementation of smart innovative solutions, based on irrigation systems that can deliver water to the fields surrounding a WWTP continuously and in a highly efficient way, can achieve a double goal: *i*) to reduce the pressure of agriculture on freshwater, while at the same time assuring a continuous source of irrigation to fully support crop water needs, and *ii*) to establish the conditions for a shift of agricultural practices towards a new peri-urban agriculture able to cope with the vulnerability of these areas (e.g. introducing new crops with high added value that can be marketed directly in the city as zero-km products).

Following the EU regulation 2020/741, reused water from WWTPs can be employed for the irrigation of different crops depending on the effluent water quality class and the irrigation method. Therefore, to foster such a new perspective on water reuse in agriculture, it is important that the "new" water is supplied together with clear and easily accessible information on its quality, which will be included within the WebGIS Acque di Lombardia, then providing the access to the website to farmers and irrigation consortia.

Specifically, for each of the 15 WWTPs mentioned above (i.e. the 15 largest plants managed by CAP in terms of treated flow, see par. 3.1), in addition to providing graphical information regarding the percentage of times the effluent is in each water quality class, further analyses were developed.

First, a set of rules was defined in order to identify the dominant water quality class for each plant, based on the previously obtained percentages (this step won't be necessary in the future when information about the water quality of WWTPs' effluents will potentially be available in real time, but it is needed for the current analysis based on the 2020 season data). An example of such rules is provided below, although criteria and thresholds can easily be changed as appropriate:

- If the effluent falls in water quality class A at least 90% of the time → the dominant class for that plant is A.
- If the effluent falls in water quality class A less than 90% of the time AND 0% of the time in class D → the dominant class for that plant is B.
- If the effluent falls in water quality class A less than 90% of the time AND below 10% in class D → the dominant class for that plant is C.
- If the effluent falls in water quality class D more than 10% of the time → the dominant class for that plant is D.

This allowed a classification of the available WWTPs according to their dominant class and, thus, application of the EU regulation 2020/741. Therefore, for each WWTP, the WebGIS can show what crop types can be irrigated with their effluent, as well as the allowed irrigation method/s.

Second, for each WWTP, the area that could potentially be irrigated using the allowed method/s was calculated as a function of their treated flow and the different irrigation methods efficiency. Specifically, the water demand was assumed to be 1.5-2.5 l/s/ha for surface irrigation, 1-1.5 l/s/ha for sprinkler irrigation, and 0.75-0.85 l/s/ha for drip irrigation (e.g. see Allen et al., 1998).

3.3 Results: a new layer for the characterisation of WWTPs

The data collected in Section 3.1 for each WWTPs have been included as attributes of the points associated to the WWTPs in WebGIS, graphically representing the percentage of each class, allowing a complete overview of the water quality of the effluents. Particularly, Figure 11 shows the entire territory managed by CAP with a pie chart with the quality classes of each of the analysed WWTPs; Figure 12 presents as an example the detailed view of Abbiategrasso plant, with the main quality information reported in the left window.

In addition to the percentage of water classes, each point of the new layer reports the average inlet flow, related to the summer and winter period, and mean values of pH, conductivity, nitrate, and ammonium concentration.

The information currently reported in WebGIS are referred to 2020, but the idea is to update the classes yearly with new data.

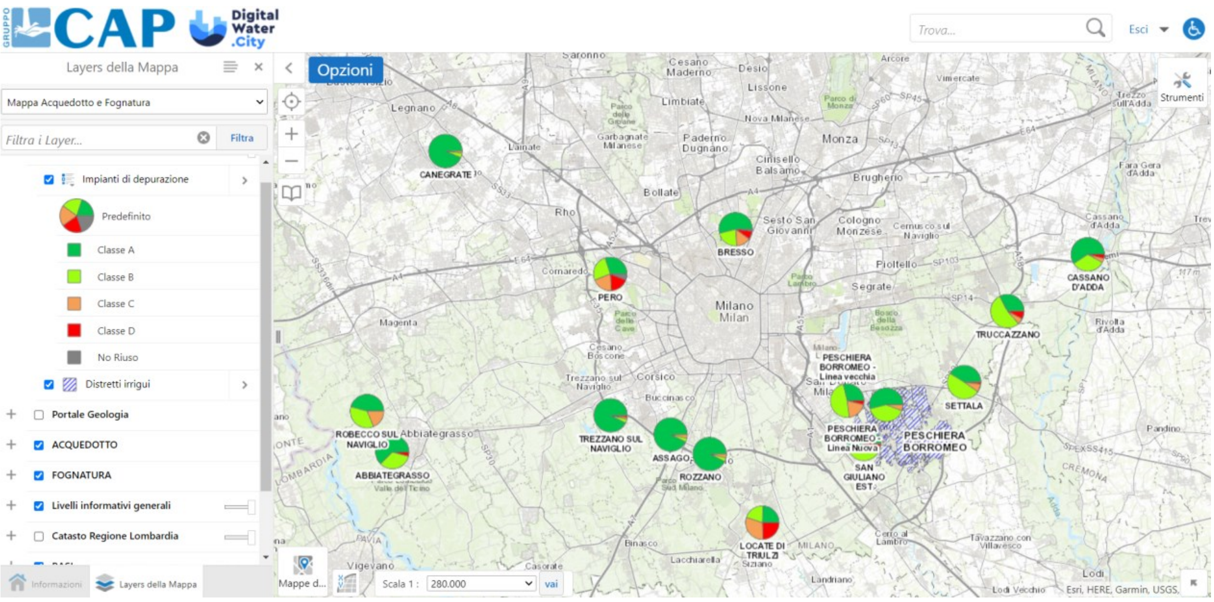

Figure 11: Implemented layers: water characterization for WWTP and purple discrict for Peschiera Borromeo plant (The image represents only a draft of the site, then subject to amendment to the final output)

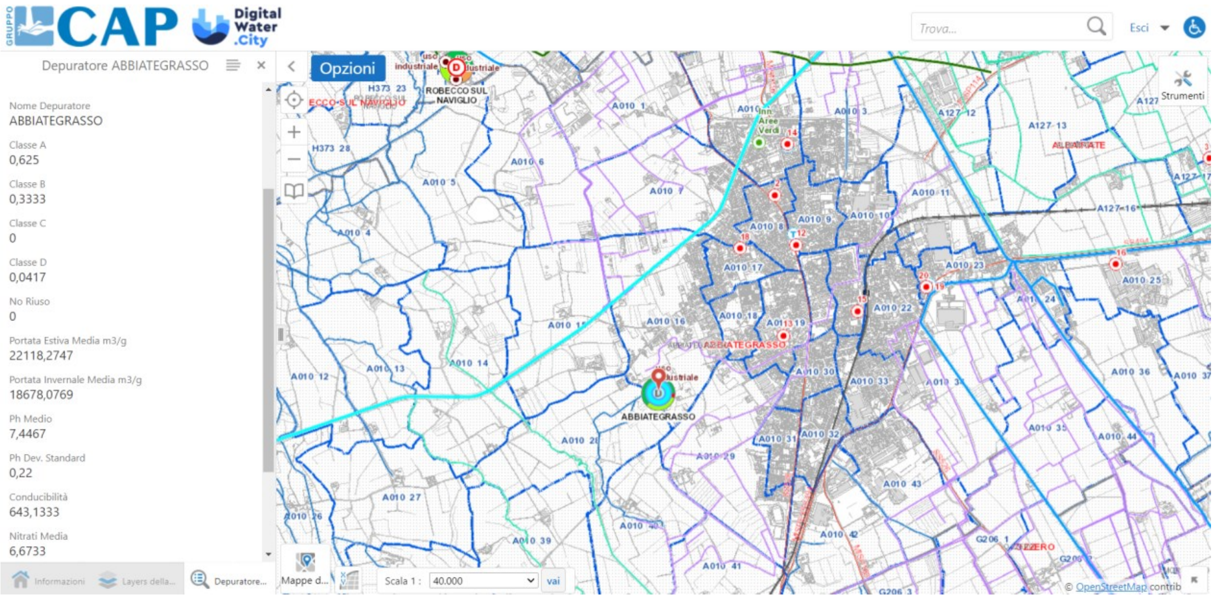

Figure 12: Detailed view of the information reported for each WWTP (The image represents only a draft of the site, then subject to amendment to the final output)

The final version of the new site of WebGIS will include information about dominant class irrigation methods and cultivable crop, as well as an additional layer with the information about areas potentially served by each WWTP.

4 Focus on Peschiera Borromeo

The location that has been set for experimental activities of DWC project is Peschiera Borromeo, located in Milan peri-urban area, as described in deliverables D1.2 and D1.3.

Peschiera Borromeo WWTP lies in Via Roma - Cascina Brusada, Milan. The plant entails two distinct treatments trains, namely Line 1 and Line 2, which treat the wastewater coming from the two sewer network sectors of the peri-urban region of Milan.

Line 1 serves the catchment that includes the peri-urban area of Milan and the municipalities of Brugherio, Carugate, Cassina de' Pecchi, Cernusco sul Naviglio, Cologno Monzese, Peschiera Borromeo, Pioltello, Segrate, Vimodrone. The East districts of Milan are served by line 2 of the plant.

The sewer network collects urban wastewater to Peschiera Borromeo WWTP and is divided in two sectors, which serve separated areas of the Peschiera Borromeo catchment and are managed by different utilities. One sector is controlled by Metropolitana Milanese and collects sewage flows from the municipalities of Brugherio, Carugate, Cassina de' Pecchi, Cernusco sul Naviglio, Cologno Monzese, Peschiera Borromeo, Pioltello, Segrate and Vimodrone. The second sector is directly managed by CAP Holding and serves the municipality of Milan and the district of Linate.

Hence, sewages coming from the area managed by Metropolitana Milanese are treated in Line 1, whereas the wastewater coming from the sewer sector controlled by CAP is treated in Line 2.

The WWTP has a treatment capacity of about 566000 PE, and treats daily an average flow rate of 216000 m^3/d. Line 1 includes coarse screening, pumping station, fine screening, grit and oil removal, primary sedimentation, biological treatment for organic carbon removal, tertiary filtration combined with nutrient removal in BIOFOR reactor and chemical disinfection with peracetic acid.

Line 2 includes pre-treatment units, specifically coarse screening, pumping station, fine screening, then a compact SEDIPAC unit for grit and oil removal coupled with primary sedimentation, followed by a BIOFOR unit for organic and nutrient loads removal combined with tertiary filtration.

BIOFOR is a reactor for biologic and nutrient removal combined with filtration and is divided into 10 modules, 5 dedicated to pre-denitrification and 5 voted to organic removal and nitrification.

The final disinfection treatment is performed with UV. In the UV disinfection unit, sensors are installed to monitor the UV light intensity. Maintenance operations are supported by a counter system with a threshold of maximum 10000 working hours for each lamp. Specific energy meters are installed to monitor UV unit.

In the final effluent, a set of probes are installed to monitor in real-time several parameters. The goal is to deploy a comprehensive network of multi-parameter sensors to monitor the contamination risk of water reuse in the Milan Peschiera Borromeo WWTP including sensors for real-time in-situ E.coli and enterococci measurements (https://www.digital-water.city/solution/sensors-for-real-time-in-situ-e-coli-and-enterococci-measurements/). Online measures are available for NH_4, PO_4, N-NO_3 and TSS measurements. A flow meter is installed to control the amount of treated water discharged.

4.1 WWTP and DWC plot description

Experimental activities in DWC were addressed to line 2 of the Peschiera Borromeo WWTP.

Peschiera Borromeo WWTP is located in the Lombardy Padana Plain. Given its geographical context, agriculture plays a key role in the economy of the region.

As previously mentioned, the most employed agriculture activities are fodder crops, such as maize. The most common irrigation techniques rely on border irrigation, implying a water demand of about 3000-4500 m^3/(ha*month) during the irrigation season.

Crop quality impacts both the quantity and quality of irrigation water because different types of crops need different amounts of water. Furthermore, the amount of water for irrigation and the frequencies of the irrigation events vary according to the period of the year. Crop quality also implies numerous risk considerations, which depend on harvesting practices, treatments accomplished to obtain the final product, and the final use of the product itself (e.g., consumed cooked or raw, consumed by humans or animals).

At present the most common sources of water for irrigation are rivers. Water is diverted from rivers and then distributed by gravity through a network of open, unlined canals and is supplied to farmers under rotation. The irrigation network of canals and the related water delivery systems are supervised by the consortium Est Ticino Villoresi, one of Italy's most important irrigation consortia.

Irrigation water availability has been traditionally adequate, but competition for water resources access in the area has been increasing in the last years and it is expected to further escalate, mostly due to a decreasing trend in summer water availability and to a reinforcement of the ecological flow requirements. Therefore, the identification of additional water resources, along with the improvement in irrigation water use efficiency, represent key issues for the next years. Alternative sources of water, such as reclaimed wastewater, are drawing attention as innovative solutions. A smart water management system would guarantee safe and good quality of reclaimed water for irrigation, and it will help satisfy the high-water demand of the agriculture sector.
To demonstrate the potential of a smart reuse of treated wastewater an experiment was carried out in the agricultural season 2021 in a field, 3.8 ha in size, adjacent to the WWTP. The field is cropped with maize during the summer season, while during autumn and winter mustard is cultivated as a cover crop. Maize was sown at the beginning of April (April 8th) and harvested on September 29th. The field has been traditionally irrigated using border irrigation with a centrifugal pump that lifts the water from a canal and spreads it over the field, but in 2021, a new drip irrigation system was installed for the purpose of the DWC experimentation. The main pipe starts from the outlet of WWTP Line 2 and reaches the field boundary where a manifold is connected.

The field is divided into four different sectors where drip irrigation can be activated autonomously through four remotely-controlled electro-valves. Each sector was irrigated for approximately 12 hours every two days during the agricultural season. At the beginning of the season, laterals, connected to the manifold, were installed in the crop inter-row with a spacing of 1.4 m and were partially buried; the emitters' distance and discharge are 30 cm and 1.14 l/h, respectively.

Figure 13: Overview of demo site (left), drip irrigation system installation (center), electro-valve regulating irrigation in each sector (right).

To obtain information about the soil water status, two multilevel humidity probes located at two points along the drippers line (yellow triangles in Figure 13, left) and a piezometric well (blue dot) with a sensor to monitor the ground table depth were installed.

In addition, a weather station was installed near the demo site to measure the local weather agrometeorological variables that are required to estimate the crop evapotranspiration; for security reasons, the station was installed inside the WWTP, about 500 m from the field (red star in Figure 13, left).

Figure 14: Sensors and devices installed: piezometer, water content probe + GSM modem, porous cups (left); agro-meteorological weather station (right).

As a reference, the same sensors (water content probes and a piezometer, yellow triangles and blue dot in Figure 13) were installed also in the adjacent field, which is cultivated with the same agronomic practices but where the irrigation is provided by border irrigation.

Moreover, DWC will deploy several digital solutions for the irrigation management (https://www.digital-water.city/digital-solutions/). Digital Solution 5.1 is an active unmanned aerial vehicle for the analysis of irrigation efficiency (UAV), working together with a conventional sensor network to monitor the effects of water stress in the soil-plant-atmosphere system. The newly gained real-time knowledge can be used to build up an early warning system to inform stakeholders and prevent microbial and toxic contamination linked to water reuse (Digital Solution 3) and to provide a serious game raising public awareness on the environmental footprint (Digital Solution 6). Data from satellite images will be also used and smart irrigation techniques are being developed from data collected to optimize irrigation practices.

4.2 Description of the potential purple district: WWTPs, irrigation infrastructure and costs

Digital Solutions in the DWC Project aim to ensure safe water reuse for agriculture from WWTPs. The treated water is generally discharged into natural watercourses where a diversion is located downstream or into an open irrigation channel to increase its discharge available for irrigation, regardless the irrigation method adopted at the field scale.

However, to maximize the benefits of the effort and energy required for depuration, the treated water could be better conveyed in a pipe pressurized distribution system that feeds high-efficiency irrigation methods at the field scale.

Such a system, limiting distribution losses and being suitable for remote control and integration with other information (obtained from ground or remote sensors) into a Digital Decision Support System can better exploit the treated water serving a larger area (for more details see https://www.digital-water.city/solution/active-unmanned-aerial-vehicle-for-analysis-of-irrigation-efficiency/ and https://www.digital-water.city/solution/match-making-tool-between-water-demand-for-irrigation-and-safe-water-availability/). The area served by such a high technology system has been defined as "purple district" to be clearly marked from the area served by the water diverted from natural rivers and characterized by the traditional irrigation management.

A first identification of a purple district has been carried out for the Peschiera Borromeo WWTP.
The boundaries of this purple district were determined considering the average treated flow (about 1 m^3/s) and the current land use, based on a preliminary estimate of the irrigation water demand of current crops.

Irrigation in the purple district is supposed to be provided by a pressurized system with drip irrigation. The realization of this irrigation system will be potentially carried out in the future, with the collaboration between CAP, as WWTP manager, irrigation consortia and reclamation manager. In particular, CAP could fund and manage the part of the system related to water supply, including storage and the potential treatment of water intended for agriculture use; irrigation consortia and reclamation manager could fund and manage the distribution system within the purple district.

The design of the irrigation network consisted of three main steps: (i) defining the irrigation network layout, (ii) calculating pipes diameters and power of the pumping system, (iii) assessing the implementation costs.

The irrigation network configuration was preliminarily obtained calculating the shortest path from the source (i.e. the output of WWTP) to each supply point (i.e. hydrants, which serve a single field or a group of fields) following, as closely as possible, the paths of the current irrigation channels (Figure 15).

Figure 15: Purple district and irrigation network overview

The design flow of each hydrant was calculated as the product of the area served by the hydrant and the water demand, assumed to be about 0.5 l/s/ha, as suggested by Allen et al., (1998) for drip-irrigated maize. Theoretical pipe diameters were calculated by maintaining the continuity equation in each node of the irrigation network and assuming a flow velocity of 1 m/s as a design standard (Kale et al., 2008).

Head losses (J) for each pipe were calculated through the Chezy-Strickler monomial formula (Becciu and Paoletti, 2010; Capra and Scicolone, 2016):

$$J = \frac{10.29}{K_s} \cdot \frac{Q^2}{D^{5.33}}$$

where k_s is thea Gauckler-Strickler friction coefficient assumed equal to 80 $m^{1/3}s^{-1}$, Q is the discharge (m^3/s) and D is the diameter (m) ..

The power of the pumping system was calculated by assuming that the hydraulic head at the hydrant in the most unfavoured position is of 30 m (minimum requirement for drip-irrigation – Ella et al., 2009).

Implementation costs were supposed to be (i) 1.600 €/kW for the pumping system, (ii) 15 €/m for pipes with diameters ranging from 10 mm to 500 mm and 25 €/m for diameters over 500 mm and (iii) 25 €/m for pipes placement.

Lastly, potential water saving was calculated considering that the radical transformation from traditional gravity-driven irrigation to drip irrigation reduces about three times the water consumption (Daccache et al., 2010).

4.3 Results: a new layer for Peschiera Borromeo purple district

For the main case study WWTP (Peschiera Borromeo), the purple district described below (i.e. the hypothetical pressurised system layout designed for drip irrigation) was also included within the WebGis Acque di Lombardia, as shown in Figure 16.

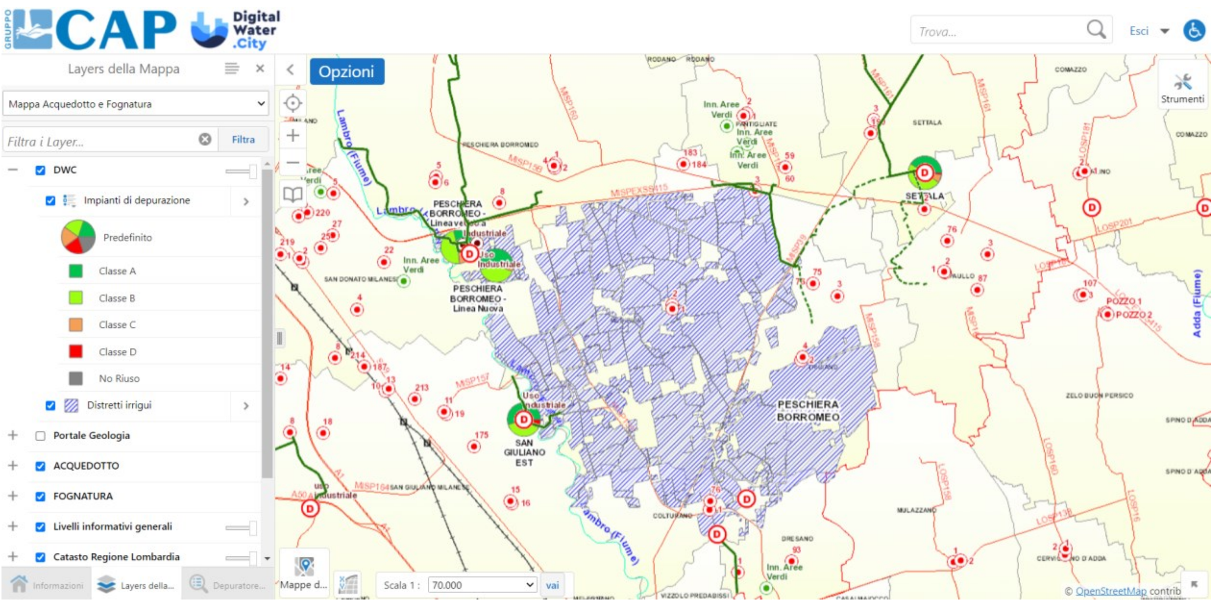

Figure 16: Purple district reported in WebGIS (The image represents only a draft of the site, then subject to amendment to the final output)

In the current version of the site, this layer includes only geometrical information about the district. In the final version of the WebGIS more details will be included, in order to show the potential reuse of treated water in a drip irrigation system.

5 Integration with Risk Management

The purpose of Risk Management is to select, plan, establish and monitor risk reduction measures. In this context, the WebGIS can be used as a tool to support risk management, since it can receive real time information about effluent water quality from the Early Warning System (EWS) in Peschiera Borromeo WWTP. In this way, decision making about water reuse can be supported and risks minimized, allowing rapid reactions in case the occurrence of a hazardous event is detected by the EWS.

WebGIS, as well as Match Making Tool (https://www.digital-water.city/solution/match-making-tool-between-water-demand-for-irrigation-and-safe-water-availability/), represents an useful tool in decision making, allowing a complete overview of risks connected to the use of reclaimed water. Match Making Tool is a communication tool, relating farmers needs and WWWTP managers resources, WebGIS is an additional descriptive tool useful to have a general overview of the supply system.

Another application of WebGIS for risk management involves the integration of data coming from the EWS and the WWTP with the information related to reuse service interruption, malfunctioning registers, infrastructure problems and irrigated fields. In these terms, WebGIS could support periodical risk assessments, including Semi-quantitative Risk Assessment (risk matrix) Quantitative Microbial Risk Assessment (QMRA) and Quantitative Chemical Risk Assessment (QCRA). Indeed, WebGIS can collect and store quality data of microbial and/or chemical concentrations, physical, radiological parameters measured in the treated wastewater, as well as providing information about the exposure pathways of target human groups to pathogens and toxicants. Exposure data include info on the irrigation method used, the quality of the cultivated crops and the presence of vulnerable exposure groups in the surroundings of the irrigated field.

WebGIS can be implemented into risk management, both as a control measure to support decision about delivering reclaimed wastewater, and as a platform that support the integrated management of the water reuse system. Particularly, WebGIS may be a very useful tool for mapping the output of the semi-quantitative and quantitative risk assessment (QMRA and QCRA) in all the irrigated field of the selected district. In this way, it can be a strategical tool to identify weaknesses within the Integrated Wastewater and Reuse System (IWRS).

The connections presented in this Section will be potentially implemented in the last part of the project due to the difficulties in integrating real time data in WebGIS.

5.1 Connection with Early Warning System to minimize risk

The WebGIS will potentially communicate with the Digital Solution 3, the Early Warning System for water reuse (https://www.digital-water.city/solution/early-warning-system-for-safe-reuse-of-treated-wastewater-for-agricultural-irrigation/), which is the solution being developed within the project to ensure that safe reclaimed wastewater is provided by the plant. The EWS provides warnings if in the plant conditions, implying that quality requirements for water reuse can be not satisfied, are detected. In these terms, the EWS can be used as a tool to support decision making, but it requires a communication to a centralized control system, and then to the WebGIS.

The rapid detection of a possible hazardous event needs an equally rapid communication to the strategy controllers of the water utility, in order to let them promptly react. In case the Early Warning System detects the possible occurrence of a hazardous event, the outcomes generated are going to be acquired by the WebGIS and read by the water utility and/or other interested stakeholders.

Hence, the water utility and/or other interested stakeholder can choose when to provide reclaimed water for irrigation or when it is needed to stop the provision of treated wastewater.

The Early Warning System is being developed in Peschiera Borromeo WWTP (for more details, see deliverables D1.2 and D1.3) to forecast water quality depending on trends and soft-sensing techniques. Particularly, Artificial Neural Networks (ANN) are being developed for time-series prediction of parameters related to wastewater quality. ANN techniques consist of processing system that connect layered structure to provide the desired output (Paquin et al., 2015). The network is fed with input data, which are combined to obtain output values through internal calculations into hidden layers (Alsulaili et al., 2021). The network is trained with some of the input and output dataset to develop the connections between them.

According to the WWTP operational conditions and/or during the occurrence of defined plant malfunctions, the EWS will be able to forecast the quantitative values of target parameters and compare them with fixed threshold (e.g., standards limit). When the forecast of a target parameter of wastewater quality exceeds the fixed threshold, a warning will be generated suggesting to stop the wastewater reuse. Predicted parameters could include:

- Total suspended solids (TSS);
- Biochemical oxygen demand (BOD);
- Chemical oxygen demand (COD).

In case of microbial hazard, particular attention must be paid to TSS concentration since solid particles may be vehicle of pathogens. Moreover, high TSS concentration could cause a decrease on disinfection performances of UV disinfection lamps.

From data collected in DWC project, it was observed that lab TSS and *E.coli* concentration measured before the UV disinfection unit, where the Alert System (i.e., the device able to monitor in real-time the *E.coli* concentrations in wastewater) was installed, can be correlated, as shown in Figure 16.

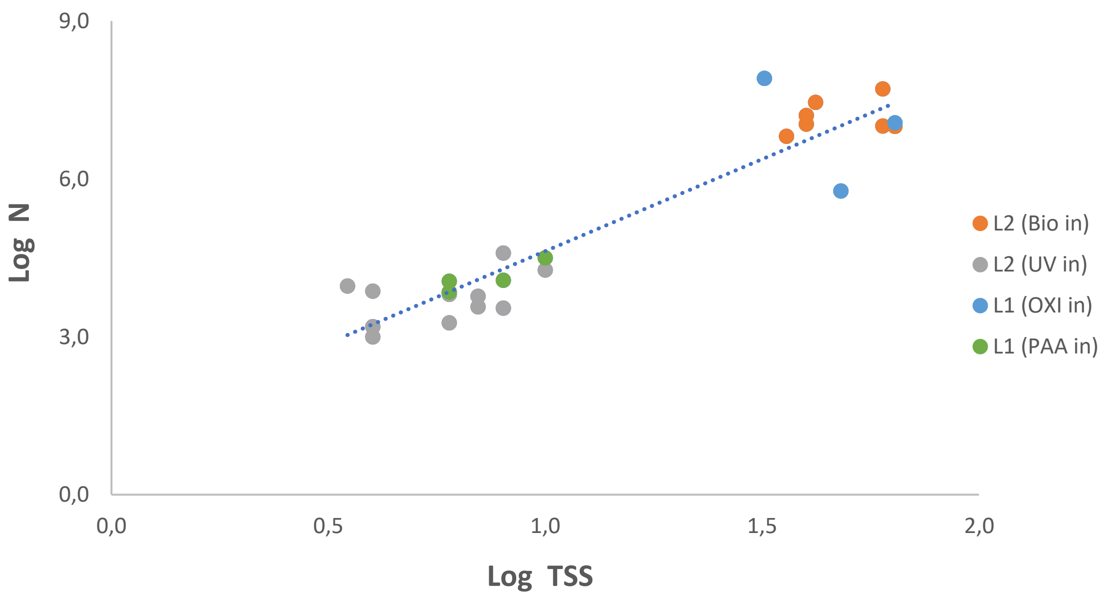

Figure 17: Correlation between E.coli (expressed as LogN) and TSS (expressed as LogTSS) lab data at different treatment stage: influent to biologic unit of Line 2 (orange); Influent to UV unit of Line 2 (grey); influent to biologic unit of Line 1(blue); influent to disinfection unit of Line 1 (green)

Predictive models of the Early Warning System require an affordable and large set of data to be trained and validated, including both periods of normal operation and periods with malfunctions occurrence, which are rarely available. Thus, predictive models are going to be developed using data from sensors, historical lab analysis data and data produced by simulation software (e.g., BIOWIN).

Particularly, the use of a modelling software allowed the simulation of specific malfunctions within the WWTP that can be cause of hazardous events for water reuse. In particular, models were used to obtain simulated data from the sensors that are actually installed at the influent or at the effluent of the WWTP,

The obtained database was used to feed and train an Artificial Neural Network (ANN). Since microbial hazards and disinfection performances are related with solid concentration, the ANN was used to obtain, as output, the TSS concentration at the effluent.

The developed network used was a feed forward neural network that, taking as inputs (simulated) sensors data could provide predictive trends of not-measured parameters, such as TSS, COD or BOD. Part of the data provided by the simulations were used to train the network (60%), while the remaining part was used to validate (15%) and test (25%) the results. First, a network was performed using 11 inputs, providing simulated data for all the sensors installed at the influent and the effluent to monitor flowrate, pH, ammonia and phosphates, temperature and dissolved oxygen in biological tank and effluent nitrates. Since all the input data could not be available all together in the plant, another ANN was performed, using this time only 6 input parameters, selecting the ones coming from the most common or affordable sensors, such as influent and effluent flowrates, pH, Temperature and dissolved oxygen in the Biofor unit.

Once the new installed sensors will provide a robust set of data, they will be used to validate the ANN with real data from the plant.

Real-time sensor data from WWTP will be ingested by a dedicated back-end deployed as a serverless application. The ingestion of data triggers the processing using a dedicate event bus. As shown in Figure 17 a dedicated function written in python runs as a function in the cloud. The lambda function uses the images stored in an Elastic Container Registry (ECR) and it makes it easier to update the code / models. The output of ANN is a timeseries that includes forecast to be used by the EWS. The EWS can then provide warnings depending on the predicted outputs.

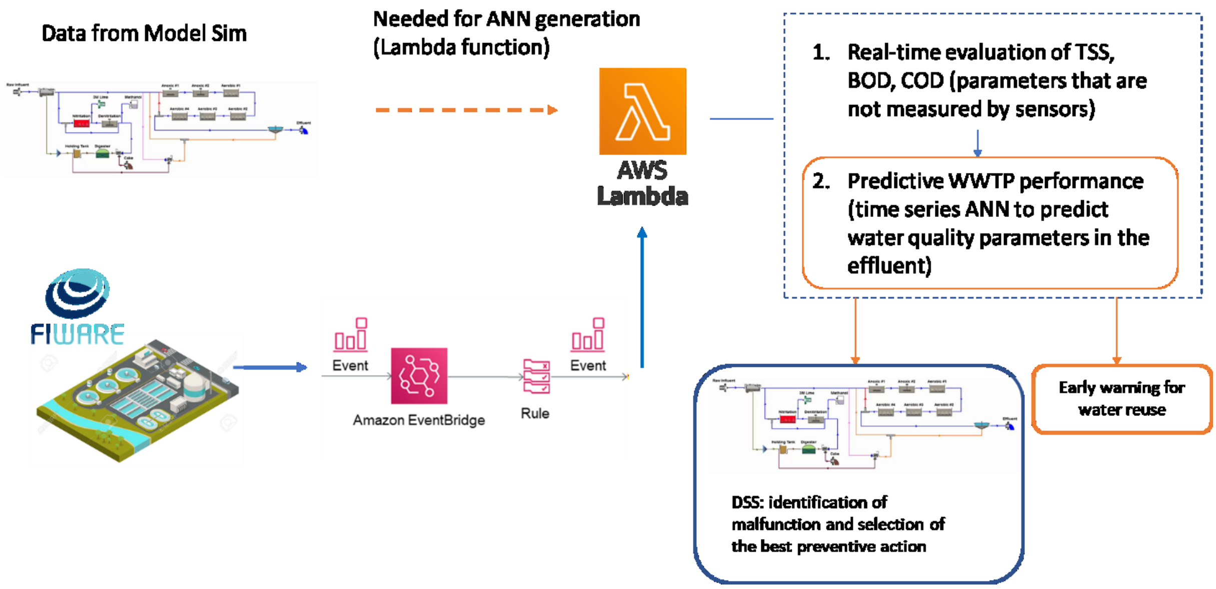

Figure 18: EWS architecture

The ANN can produce for the WebGIS information about predicted effluent wastewater quality. The warning provided by the EWS can be communicated to the WebGIS, which will indicate if the plant is able to provide reclaimed wastewater for reuse applications.

Further developments and improvements could be obtained integrating the monitoring network of sensors and probes installed at Peschiera Borromeo WWTP with online measurements of *E.coli*, using the Alert System device. Alert System can provide almost in real-time measures of *E.coli* and total coliforms in wastewater. It has a response time of 2-12 hours, much shorter than the 24-48 hours required for lab analyses. Moreover, samplings can be scheduled and customized remotely.

The Alert System could give inputs to the Early Warning System, which will analyse the received data and provide warnings or alarms. In addition, according to predictive measurements of wastewater quality by the EWS, timely measurements by the Alert system can be scheduled.

5.2 Potential improvements and connection with Quantitative Microbial and Chemical Risk Analyses

WebGIS could be used as a control measure to support rapid decision making by acquiring the outcomes of the Early Warning System from the WWTP.

However, WebGIS could also support periodical risk assessment for water reuse, since it is able to manage both quality data from the WWTP and information related to agricultural practices in the surrounding areas. In these terms, it represents a support tool for an integrated management and planning of water reuse.

WebGIS could include all the information collected for the EWS definition. Semi-quantitative risk assessment (Risk Matrix) and quantitative approaches for microbial (QMRA) and chemical (QCRA) risk assessment require progressive steps of hazard identification, hazard characterization, exposure assessment and risk characterization. Pathogen and/or chemical concentrations, physical and/or radiological parameters, infrastructure problems, routes of exposure for different targets, and the effects of technological, practice or behavioral barriers on risk minimization must be taken into account.

In order to perform a QMRA, reference pathogens or indicators must be characterized and log removals along the irrigation systems should be considered. According to WHO, reference pathogens such as Campylobacter, Criptosporidium and Rotavirus can be selected to evaluate microbial contamination. However, since their determination is not always feasible and not much data are usually available from analytical measurements, indicators such as *E.coli* could be used to evaluate the microbial risk of infection for humans. In Peschiera Borromeo WWTP, reference pathogens are not usually measured, while historical data for *E.coli* measurements are available and the dataset is continuosly extended by periodical lab analysis and measurement campaigns. *E.coli* concentrations can thus be used to perform QMRA. The population target for the risk analysis must be identified, and it may include plant operators, field workers, local community and consummers. Different exposure scenarios could be performed for the individuated exposure groups and dose-response models could be used to quantify the probability of infection according to the EPA or WHO guidelines.

Statistics tools, such as Monte Carlo Analysis, can be used to support quantitative risk assessment. Probability distribution functions can be fitted with the trends of available data to evaluate the risk. The WebGIS can collect all the *E.coli* measures periodically performed in the plant, increasing continuously the amount of data available. In this way, probability functions can be fitted using a higher amount of measured data improving the risk evaluation.

Since risk assessment requires an integrated approach, data from the irrigated district are required to define all the possible exposure routes and exposure scenarios for the target population groups.

WebGIS can provide information about cultivated crops, irrigation techniques, soil characteristics and nearby exposed population of the irrigated areas.

Quantitative Chemical Risk Assessment can be performed to evaluate heath-risks due to micropollutants (e.g., pesticides or heavy metals) presence in wastewater. For each considered contaminant, a risk quotient can be calculated as the ratio between the concentration at the end-point of exposure and the tolerable concentration, expressed as predicted no-effect concentration (PNEC) (Seis et al., 2012).

Even in this case, WebGIS can support providing historical measures of wastewater quality, as well as information about the irrigated district and the characteristics of cultivated crops and soils, in order to evaluate toxicity for humans and plants.

All the data required for the implementation and periodic updates of QMRA and QCRA can be included into the WebGIS. Output of the QMRA and QCRA for all the irrigated field of the district and target groups of people can be mapped to support the integrated management of water reuse.

6 Conclusions

This document reports information about the implementation of DS4, the WebGIS, as a tool to share and analyze data on treated wastewater reuse for agricultural use.

Water reuse for agriculture is a topic that has to take into account several aspects, requiring specific attention on health-risks evaluations. For this reason, it is important to have a proper monitoring plan of the whole utilization cycle, to detect potential critical points. The WebGIS structure presented in this document provides a complete overview of the Integrated Wastewater and Reuse System (IWRS), including tools able to support it.

WebGIS Acque di Lombardia is a platform developed by Gruppo CAP to manage the geo-referred data of the Integrated Water Service of Water Alliance. In the present version, it includes information about aqueduct and sewerage networks, wells, treatment plants as well as geological and hydrogeological data.

Within the DWC project, a new site of WebGIS Acque di Lombardia is developed in order to create a complete platform, including the main information about the quality of the treated water, the cultivable areas, allowed crop categories and irrigation methods. The "Regulation (EU) 2020/741 of the European Parliament and of the Council on minimum requirements for water reuse" establishes limits on water quality depending on the method used to irrigate crops and irrigation techniques and defines four quality classes. Starting from the quality parameters of treated water measured through laboratory tests during 2020, an analysis of the 15 biggest wastewater treatments plants managed by CAP has been carried out.

In addition, for each of the WWTPs, a set of rules is introduced for associating a dominant class to the plant. In such a way, WebGIS can report the crop type and irrigation methods potentially allowed. This analysis provides an overview of the available reclaimed water, representing the first level of information useful to the users for planning the cultivations of the next agricultural season. Finally, for each plant, indications about the potentially irrigated areas are reported as a further indication for farmers.

A more detailed analysis is carried out for the case study of Peschiera Borromeo, for which the WebGIS reports a specific layer about the purple district, which describes the precise area that can be potentially served by a pressurized system with drip irrigation.

For Peschiera Borromeo case study, the new site of WebGIS will be connected with the Early Warning System (DS3), to ensure a continuous risk assessment. In this way, the user will be informed in case of a warning on the quality of reclaimed water. The Early Warning system, using an Artificial Neural Network is able to forecast water quality depending on trends of parameters measured by sensors.

WebGIS could be useful in risk management also integrating Quantitative Microbial Risk Assessment (QMRA) and Quantitative Chemical Risk Assessment (QCRA), collecting data of concentrations measured in treated water ad mapping the output of QMRA and QCRA in all the irrigated field of the selected district. In such a way, it can be a tool to detect weakness in the risk management of the whole area of CAP.

7 Bibliography

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. 1998.

Alsulaili, A.; Refaie, A. Artificial neural network modeling approach for the prediction of five-day biological oxygen demand and wastewater treatment plant performance. *Water Supply* 2021, *21*, 1861–1877, doi:10.2166/ws.2020.199.

Becciu G and Paoletti A. Fondamenti di Costruzioni Idrauliche. Milano, UTET. 2010.

Capra, A. and Scicolone, B. Progettazione e gestione degli impianti di irrigazione: criteri di impiego e valorizzazione delle acque per uso irriguo, Bologna, Edagricole. 2016.

D.Lgs. n 152 *D.Lgs. n 152*; 2006.

Daccache, A., Lamaddalena, N., and Fratino, U. On-demand pressurized water distribution system impacts on sprinkler network design and performance. Irrigation Science, 28(4), 331–339. 2010

Ella, V., Reyes Reyes, M., and Yoder, R. (2009) Effect of Hydraulic Head and Slope on Water Distribution Uniformity of a Low-Cost Drip Irrigation System. Applied Engineering in Agriculture, 25(3), 349–356.

EPA Guidelines for Water Reuse 2012 EPA/600/R-12/ 618. 2012.

EU Regulation *REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 May 2020 on minimum requirements for water reuse*; 2020; Vol. 2019.

Kale, R. V., Singh, R. P., and Mahar, P. S. Optimal Design of Pressurized Irrigation Subunit. Journal of Irrigation and Drainage Engineering, 134(2), 137–146. 2008.

Paquin, F.; Rivnay, J.; Salleo, A.; Stingelin, N.; Silva, C. Multi-phase semicrystalline microstructures drive exciton dissociation in neat plastic semiconductors. *J. Mater. Chem. C* 2015, *3*, 10715–10722, doi:10.1039/b000000x.

Seis, W.; Water, V.; Wasserbetriebe, B. Risk assessment of Braunschweig wastewater reuse scheme. 2012.

WHO *Quantitative Microbial Risk Assessment: Application for Water Safety Management*; 2016.

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